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Ranking Sewage Treatment Plants with the Application of Fuzzy Composite Programming

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Abstract: ***The present study rank six sewage treatment plants receiving sewage from the different zones of city. Were the wastewater was analyzed for solids, organic and inorganic parameters. The removal is observed in solids and organic parameters, while there is increase in inorganic parameters. The efficiency is evaluated considering overall effect of eight parameters and weights are assigned as per the importance of each parameter in treatment process. The Multi Parameter aggregated Index (MPAI) is developed by Fuzzy approach. Karanj STP is ranked first with 58.30 % efficiency while Bamroli STP is ranked last with very poor efficiency. Considerable uncertainties are involved in the process of defining the treated wastewater quality for specific usage.***

Key words: Sewage treatment plants, MPAI, Uncertainty, Fuzzy composite programming, Efficiency.

1. Introduction

According to Vandeweerd et al. (1997), about 90% of sewerage is discharged without treatment into lakes, rivers, and coastal waters bodies from developing world. The treatment methods were developed to answer the health issues of community and for the poor situations caused due to the waste water discharge off in environment (Jamrah 1999).The correct wastewater treatment produce the effluent meeting to the desired guidelines in microbiological and chemical quality with minimum cost in operation and maintenance (Arar 1988). Comprehensive study of sewage treatment plan was carried out by Jamwal et al.(2009) ,Colmenarejo et al.(2006) ,Sudasinghe et al. 2011, Alaton et al.(2009) and Fatma (1988).

The current practice is to evaluate the performance of the STP by the removal of various parameters during the treatment. This reflects the individual parametric removal efficiency. However it is worth noting that all the parameters together will have a degrading effect on the surface water environment. Moreover, the environment itself is an interlocking system operating in the state of dynamic equilibrium, the unity concept of pollution is more appropriate to be applied rather than the individualistic approach as practiced today. Therefore an attempt has been made to develop a wastewater quality index for evaluating overall strength of raw and treated wastewater by fuzzy model employing Fuzzy composite programming (FCP) technique. The performance of treatment plant is evaluated with Multi Parameter Aggregated Index (MPAI) for raw and treated wastewater.

2. Methodology

Modeling is an integral part of most decision making process. The modeling of evaluating performance of treatment plant under different treatment conditions assumes greater complexity due to the involvement of human behavior in decision making process in its evolution. It is felt that a method should be developed to quantify the strength of wastewater on the basis of its monitored characteristics of different parameters. If one is able to quantify the strength of wastewater before and after treatment in a form of index, the true efficiency of the STP can be effectively measured.

2.1Fuzzy Composite Programming (FCP) approach

This multi-objective analysis of STPs includes uncertainties in terms of fuzzy membership function and interval numbers (the lowest and highest likely range). The membership in the sets cannot be defined on a scale of yes/no in fuzziness as the boundaries of the sets are unclear in this case. The membership degree for a vague value can be found by "expert judgment" based on knowledge and practical experience (Stanbury et al., 1991). In this study for developing membership functions of fuzzy numbers, Interval estimation was applied because of its simplicity and less calculation required. Uncertainty analysis or fuzziness in evaluating efficiency of STP was included to take into account the vagueness in the data range. The composite procedure involves a step-by-step regrouping of a set of various basic indicators to form a single indicator. Figure 1 shows the hierarchy composite structure of the basic indicators selected for finding the overall efficiency of STP which is self-explanatory.

2.2Normalizing the Basic Criterion, Determination of weights and Balancing factor

The membership function for each of the basic criteria can be constructed, where Zi,h(x) is an interval value of the ith basic criteria at the confidence level (membership degree) h, [i.e., a $\le Z_{i,,h}$ (x) $\le$b]. The best and worst value for the basic criterion is determined by expert's perceptions. Using the best value of $Z_i(BESZ_i)$ and the worst value of $Z_i(WORZ_i)$

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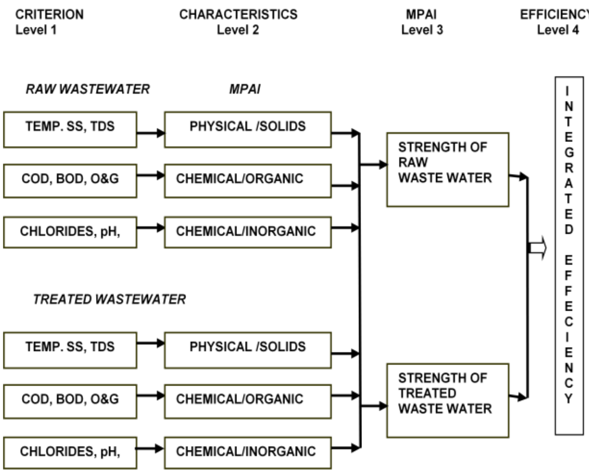

Fig. 1: Hierarchie for the Integrated Efficiency of STP by FCP

for the ith basic indicators, the actual value $Z_{i,,h}(x)$ is transformed into an ithnormalized basic criterion value. The actual value $Z_{i,,h}(x)$ is transformed into an index value denoted by $S_{i,,h}(x)$. In the model for evaluating the MPAI the $\mathbf{Z_{i+}}$ is minimum value ie. $BESZ_i$ in data and $\mathbf{Z_{i-}}$ is maximum value ie. $WORZ_i$ in observed data. The normalize values for field data is determined by the following equation 1 (Bogardi, 1992).

$$\mathbf{S_i} = \frac{\mathbf{Z_i - Z_{i-}}}{\mathbf{Z_{i+} - Z_{i-}}} \quad (1)$$

where S_i is normalized i_{th} fuzzy indicator; Z_i is value of ith fuzzy indicator; Z_{i+} is maximum possible value of i_{th} indicator and Z_{i-} is minimum possible value of i_{th} indicator. The composite distance was computed by the following equation 2 (Bogardi, 1992)

$$Lj,h(x) = \sum_{i=1}^{Nj} \left\{ Wij\,[\mathrm{S\,i,h,j(x)}]^{Pj} \right\}^{\left(\frac{1}{Pj}\right)} \quad (2)$$

Where Lj, h(x) is fuzzy composite distance in group j, nj is the number of elements in the first level group j; Si,hj(x) is the index value for the ith indicator in the first level group j of basic indicators; wij is the weight reflecting the importance of each basic indicator in the first level group. Pj= the balancing factor for the first level group j. The index values, $L_{j,h}(x)$ and $L_{k,h}(x)$ of the second and third level indicators respectively can be calculated using appropriate formulae.

To calculate the weight for different indicators (parameters) weights are selected as per Saaty's scale. Pair wise comparisons are used determines the relative importance of each alternative in terms of each criterion. To compare indicator i with indicator j, the decision maker assigns values aij suggested in AHP paired comparison method. Then proceeds as follows: If the degree of importance of the parameter i relative to j is represented by 1) if aij= r, then aji=(1/r) where r ≠ 0, and i ≠ j. 2) If i =j, then aij= aji=1. 3) Construct matrix [A] = (aij| wher i=1,.. . , m; j=1, . . . ,m). Saaty (1988) has shown that the eigenvector corresponding to the maximum eigen value of matrix A is a cardinal ratio scale for the indicators compared. The eigen value problem is solved by equation 3.

$$A*W=\Phi_{max}*W \quad (3)$$

Moreover, the unit eigenvector, (W) corresponding to Φ_{max} yields the preference weights for the criteria compared. The maximal deviation is presented by balancing factor p between the indicators of same group. The normal values used for balancing factors in equation are one and two. In this study balancing factor considered is 1.

3. Materials and Methods

The sewage treatment plants under analysis are located at Anjana, Bhatar, Singanpore, Karanj, Bhesan and Bamroli in Surat. The treatment technologies are conventional activated sludge system except Bamroli. Bamroli STP is furnished with UASB treatment technology. An intensive program of sampling and analysis of the raw wastewater, and the treated wastewater, with physicochemical analysis and bacteriological examinations of the wastewater were conducted according to American Standard Methods devised by American Public Health Association (1992).

4. Results and Discussion

STP exhibited different physical, chemical and biological efficiencies depending upon the characteristics of influent, HRT, percentage of capacity utilization, etc. Therefore the need is to define a common parameter or index that could determine the overall efficiency of STP in terms of aggregation of physical, biochemical and microbiological removal efficiencies. This will also help in making decisions for efficient reuse of effluent. The criterions selected for study are Temperature, TDS, SS, BOD, COD, O&G, Chlorides and pH. Wastewater is chlorinated before discharge hence FC and FS are not considered in present study. For case studies average values of raw and treated wastewater data for different parameters, from different STPs located at Surat is considered. Table 1below presents the average values of eight parameters; for raw as well as treated wastewater. The criterions (data of different parameters) were normalized using Equation 1–2. The Worst (maximum possible values) and Best (minimum possible values) were determined from statutory norms set by governing authorities, Table 2 presents the most likely (Best) and maximum likely (Worst) values for different raw and treated criterion of wastewater. These criterions are described by GPCB for discharging treated

wastewater in surface water sources. With the help of Equation 1 the $S_{i,j}(x)$; Normalized fuzzy value of first level indicator are determined

Table 1: Average values of Raw and treated wastewater at six STPs

Parameters →	Temp.	TDS	SS	BOD	COD	O&G	Cl	pH
ANJANA: 82.5 MLD, Conventional ASP								
Raw	25.96	658.56	626.98	584.53	1192.56	7.54	277.84	7.26
Treated	26.31	735	35.11	18.33	91.78	0	303.62	7.59
BHATAR: 120 MLD, Conventional ASP								
Raw	29.42	1933.96	176.96	151.13	320.91	7.14	279.56	7.23
Treated	29.24	1057.64	22.73	17.47	87.91	0.67	328.44	7.41
SINGANPORE: 100 MLD Conventional ASP								
Raw	29.14	697.18	359.18	369.11	788.4	7.05	288.78	7.23
Treated	28.47	735.31	34.33	27.13	108.76	0.66	310.11	7.67
KARANJ: 100 MLD Conventional ASP								
Raw	28.81	1915.81	430.65	223.51	520.48	7.18	475.4	7.22
Treated	28.31	1051.62	25.58	17.29	17.29	0.67	321.56	7.35
BHESAN: 100 MLD Conventional ASP								
Raw	24.73	1463.52	287.68	183.88	385.63	7.12	294.61	7.51
Treated	24.69	1469.12	69.61	28.44	146.19	0.66	218.74	7.79
BAMROLI: 100 MLD UASB + Extended Aeration								
Raw	25.03	676.21	300	235.21	603.85	7.14	257.09	7.21
Treated	25.02	733.47	88.13	30.53	109.69	0.67	287.44	7.21

Table 2 :Best and Worst Indicator Values for Criterions.

Criterions	Best values	Worst values
Temperature ^{0}C	0	40
TDS mg/L	0	2100
SS mg/L	0	100
BOD mg/L	0	30
COD mg/L	0	100
O&G mg/L	0	10
Chlorides mg/L	0	600
pH	7	0

4.1 Determination of Weights and Balancing factors at Second and Third level

For sensitivity analysis, weights for all three trials were determined by the researcher. Weights (w_{ij}) represent the relative importance between indicators in given group. Greater the importance of an indicator, greater is the weight assigned to it. The preference weights are obtained for each of the first level indicators. In order to show how preference weights are obtained, the procedure, called analytic hierarchy process (AHP), is be used. Each of first-level indicators such as Temperature, TDS and SS (Figure 1) is compared in pair-wise manner using Saaty's weights. The 3 × 3 matrix "A" can be constructed. Weights for three trials are determined. Three trials were run with different weights to determine differences in the final decision index for raw as well as treated wastewater which shows the different perceptions of the importance of each criterion (three different weights for three individual trials). For comparing several STPs the weights and balancing factors are required to be identical. For sensitivity analysis results are compared with three trials with different weights and balancing factors. Similarly weights, W for three trials are determined where CR is always less than 0.01.The weights and balancing factors for two hierarchy levels with three trials are shown below in Table 3.

Table 3: Weights used at Second and Third Hierarchy Levels for Three Trials.

Levels	Criteria	Trials for W			p
		1	2	3	1, 2, 3
2	Temp.	0.09	0.08	0.07	1
	TDS	0.25	0.27	0.30	1
	SS	0.66	0.65	0.63	1
	BOD	0.40	0.47	0.43	1
	COD	0.40	0.38	0.43	1
	O&G	0.20	0.15	0.14	1
	Cl	0.17	0. 20	0.15	1
	pH	0.83	0. 80	0.85	1
3	Characteristics	1	2	3	1, 2, 3
	SOLIDS	0.29	0.333	0.33	1
	ORGANIC	0.35	0.333	0.41	1
	INORGANIC	0.36	0.333	0.26	1

The Lj, h(x), for second level is determined, with the help of Equation 2. The Si h(x) and Wi,j values would be the input ,the Lj, h(x) values are presented in Table 4 below. Further, the index values, Lk, h,(x), of third-level

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composite indicators can be calculated by using the index values for second-level composite indicators, which is as

Table 4: $L_{j,h,k}(x)$, Second Hierarchy Level for Three Trials

STP		Solids			Organic			Inorganic		
		Trial- 1	Trial-2	Trial-3	Trial- 1	Trial-2	Trial-3	Trial- 1	Trial-2	Trial-3
1.	Raw	0.8279	0.8174	0.7801	0.9434	0.9459	0.936	0.2226	0.2313	0.2168
	Treated	0.3693	0.3785	0.3688	0.5748	0.5809	0.5565	0.4125	0.4159	0.4102
2. 2	Raw	0.9667	0.9588	0.9501	0.9342	0.9371	0.9256	0.2065	0.2159	0.2002
	Treated	0.3183	0.3334	0.3349	0.5647	0.5699	0.5492	0.3199	0.3281	0.3144
3.	Raw	0.8367	0.8286	0.7906	0.9322	0.9351	0.9233	0.2091	0.2189	0.2025
	Treated	0.3669	0.378	0.3675	0.744	0.7524	0.7189	0.4586	0.4607	0.4572
4.	Raw	0.9639	0.9555	0.9467	0.9351	0.938	0.9267	0.2564	0.2758	0.2435
	Treated	0.3368	0.3504	0.351	0.322	0.3271	0.3067	0.2848	0.2939	0.2787
5.	Raw	0.9104	0.899	0.8814	0.9338	0.9366	0.9251	0.3657	0.3702	0.3627
	Treated	0.6921	0.6898	0.6846	0.7628	0.7716	0.7364	0.4991	0.4942	0.5024
6.	Raw	0.8284	0.8172	0.7807	0.9342	0.9371	0.9256	0.189	0.1977	0.1833
	Treated	0.7489	0.7412	0.7109	0.7854	0.7947	0.7574	0.1976	0.2078	0.1909

shown in Equation 4 shown below:

$$L_{k,h}(x) = \sum \left\{ {}_{i=1}^{n_k} w_{ij} \left[L_{j,h,k}(x)\right]^{p_k} \right\}^{\frac{1}{p^k}} \qquad (4)$$

Where, n_k = the number of elements in the third level group k; $L_{j,h,k}(x)$ = the index value for the second- level group j in the third- level group k; w_{ij} = the weight expressing the importance among elements in the third level group k, p_j= the balancing factor for the third level group j. The $L_{k,h}(x)$ of third-level composite indicators for three trials is shown in Table 5 below. This is MPAI for raw and treated wastewater.

Table 5: MPAI for Raw and Treated wastewater $L_{k,h}(x)$

STP	MPAI	Trial- 1	Trial -2	Trial -3
Anjana	Raw	0.6940	0.7113	0.6929
	Treated	0.4558	0.4611	0.4509
Bhatar	Raw	0.7346	0.7578	0.7459
	Treated	0.4075	0.4172	0.4110
Singan pore	Raw	0.6891	0.7084	0.6881
	Treated	0.5293	0.5343	0.5244
Karanj	Raw	0.7484	0.7725	0.7563
	Treated	0.3164	0.3273	0.3154
Bhesan	Raw	0.7608	0.7750	0.7632
	Treated	0.6616	0.6684	0.6569
Bamroli	Raw	0.6811	0.6993	0.6805
	Treated	0.6022	0.6218	0.5934

Overall Efficiency of STP for three trials is shown in figure 2. The efficiency is calculated by Equation 5.
Effciency = (Input-Output)/ Input* 100

OR

$$\frac{MPAI_R - MPAI_T}{MPAI_R} X\ 100 \qquad (5)$$

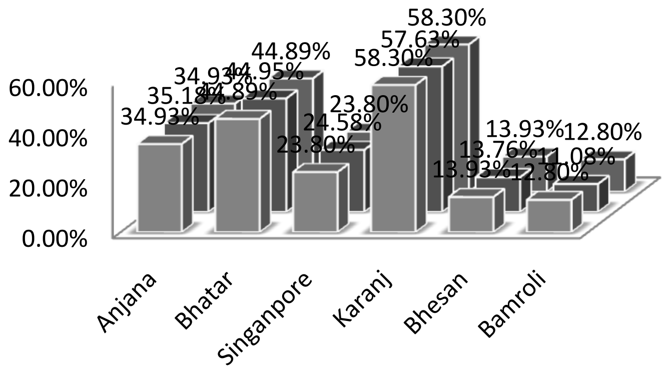

Fig. 2: Sensitivity analysis for estimating robust ranking order.

4.2 Application of MPAI for Wastewater Reuses

It shows that if the treatment plant runs with an efficiency of 48.85 %, the treated water can be reused for irrigation. Moreover if the efficiency of the treatment plant is 71.30 %, 83.34 % and 90.37 % the treated wastewater can be reused for fishery, as mineral water and as reverse osmosis (RO) treated water respectively.

5. Conclusion

The present study has been designed to determine the integrated efficiency of Sewage Treatment Plants through wastewater quality index. In this study, a new index MPAI for raw and treated wastewater has been developed. The index developed is a scalar value by analyst's judgment, expert human knowledge, experience and available literature. Quantification of this index is subjected to uncertainties for many reasons including difficulties in defining input and output parameters and consequences of severity and mathematics of combining them.

The modified fuzzy-composite programming method can be a useful decision making tool where there are conflicting objectives, the objectives are of varying degrees of importance; and the values of the basic indicator variables are uncertain.

Figure 6 shows that Karanj treatment plant shows 57.73 % efficiency with 1st rank while Bamroli shows 11.58 % efficiency with 6 th rank. Bamroli STP receives domestic and industrial wastewater and shows overall efficiency very poor.

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